Date: 02/04/04 Express Mail Label No. EV 214952 608 US

Inventors: LeNoir E. Zaiser and Kevin Confoy

Attorney's Docket No.: 2173.2007-001

FLUID PUMP

RELATED APPLICATION

This application claims the benefit of U.S. Provisional Application No. 60/445,358, filed February 5, 2003. The entire teachings of the above application are incorporated herein by reference.

BACKGROUND

Some patients that require supplemental oxygen for breathing are able to conduct their daily activities by transporting a portable pressurized oxygen tank with them. Such oxygen tanks typically contain oxygen that is pressurized to about 2200 psi. Patients who live at home must be able to replace the tanks or have a means for refilling the tanks when the tanks become depleted.

SUMMARY

Embodiments of the present invention include a pump that is capable of pumping fluid under pressure in an efficient manner and is suitable for refilling oxygen tanks in a home setting.

One particular embodiment includes a pump that can have a housing and a first piston positioned within a first chamber in the housing. The first chamber can have a first inlet and a first outlet. A second piston can be positioned within a second chamber in the housing and secured to the first piston. The first and second pistons each have a diameter, with the diameter of the first piston being larger than the diameter of the

second piston. The second chamber has a second inlet and a second outlet. The second inlet can be in communication with the first outlet of the first chamber.

A drive system reciprocates the first and second pistons in unison within the first and second chambers such that when the first piston is moving in an expansion stroke, fluid can be drawn into the first chamber through the first inlet. At the same time, the second piston is moving in a compression stroke where fluid can be expelled from the second chamber through the second outlet. When the first piston is moving in a compression stroke, the second piston is moving in an expansion stroke where fluid can be expelled from the first chamber through the first outlet and into the second chamber through the second inlet.

In particular embodiments, a connecting member can secure the first and second pistons together in a spaced apart manner along a common axis and extends between the first and second chambers. The connecting member can include a threaded screw. The drive system can include a rotatable nut engaged with the threaded screw and a reversible motor for alternately rotating the nut in opposite directions to cause reciprocating linear translation of the connecting member and pistons. The rotatable nut can be a ball screw nut.

A check valve system can be included for preventing back flow through the pump so that fluid flows in one direction. The check valve system can include a first check valve for preventing fluid from exiting the first chamber through the first inlet, a second check valve for preventing fluid from exiting the second chamber through the second inlet, and a third check valve for preventing fluid from entering the second chamber through the second outlet.

A piston position sensing system can be included for sensing piston position. In addition, pressure within the first chamber can be sensed by a first pressure sensor, and pressure of fluid expelled from the second chamber can be sensed by a second pressure sensor. The diameters of the first and second pistons can have a difference in size of about a 3.5 to 1 ratio. In one embodiment, the diameter of the first piston can be about 4 inches, the diameter of the second piston can be about 1.127 inches, and the stroke of

the first and second pistons can be about 6 inches. A pump with such dimensions is capable of pumping about .5 $in.^3$ of gas at about 2200 psi per cycle.

In embodiments of the pump, using a drive system with a low friction ball screw, reciprocating the pistons in unison, and pumping the gas in two stages for increasing pressure, allows gases such as oxygen to be pumped under pressure into a tank with the use of a relatively small motor which minimizes the use of power and the generation of heat.

BRIEF DESCRIPTION OF THE DRAWINGS

The foregoing and other objects, features and advantages of the invention will be apparent from the following more particular description of embodiments of the invention, as illustrated in the accompanying drawings in which like reference characters refer to the same parts throughout the different views. The drawings are not necessarily to scale, emphasis instead being placed upon illustrating the principles of the invention.

FIG. 1 is a schematic drawing of an embodiment of a pump with the first stage piston in an open position for drawing in low pressure gas and the second stage piston in a discharge position for forcing gas into a tank at a higher pressure.

FIG. 2 is a schematic drawing of the embodiment of FIG. 1 with the first stage piston in a discharge position and the second stage piston in an open position, whereby gas from the first stage chamber is forced into the second stage chamber.

DETAILED DESCRIPTION

Referring to FIG. 1, a pump 10 is an embodiment of a pump for pumping fluid, such as gases, and is shown pumping low pressure oxygen received through a line 22 from a home oxygen concentrator 20 into a pressurized tank 52 through a line 46.

The pump 10 includes a first stage piston 14 which reciprocates within a first stage chamber 12, and a second stage piston 18 which reciprocates within a second stage chamber 16. The first stage piston 14 and chamber 12 are larger in diameter than

the second stage piston 18 and chamber 16. The first 14 and second stage 18 pistons are secured to each other by a threaded screw 38 and positioned in line with each other along a longitudinal stroke axis A. The threaded screw 38 is connected to a drive system 45 having a rotating ball screw nut 42 which drives the threaded screw 38 in alternating directions for reciprocating the first 14 and second 18 stage pistons in unison within the first 12 and second stage 16 chambers. The drive system 45 is controlled by a controller 62 in electrical communication thereto. The threaded screw 38 extends along axis A between the first 12 and second 16 stage chambers and passes through a connecting passage 44 that extends between chambers 12 and 16.

The first stage chamber 12 has a first inlet 27 for allowing gas to enter chamber 12. A first check valve 24 of a check valve system is positioned upstream of inlet 27 in close proximity thereof to prevent gas from exiting the first stage chamber 12 through inlet 27. An inlet pressure sensor 26 that is in communication with controller 62 is included between inlet 27 and check valve 24 for sensing the entering gas pressure. The first stage chamber 12 also has a first outlet 28 which is communication with the second stage chamber 16 through a second inlet 58 by a passage 30 extending therebetween. A second check valve 32 of the check valve system is positioned upstream from the inlet 58 in close proximity thereof for preventing gas from exiting the second stage chamber 16 through inlet 58. The second stage chamber 16 has a second outlet 60 through which gas exits the chamber 16. A third check valve 48 of the check valve system is positioned downstream from the outlet 60 to prevent gas that is pumped therethrough from reentering the second stage chamber 16 through outlet 60. An outlet pressure sensor 50 that is in communication with controller 62 is positioned downstream from check valve 48 for sensing the exiting gas pressure.

When pumping oxygen such as in the configuration shown in FIG. 1, low pressure oxygen enters the first stage chamber 12 of pump 10 from home oxygen concentrator 20 via line 22, check valve 24 and inlet 27 while the first stage piston 14 is in the open position as shown. When the inlet pressure sensor 26 senses that the oxygen has reached a certain predetermined level, controller 62 activates drive system 45 to

move the first 14 and second 18 stage pistons in unison to the other side of their respective chambers 12 and 16 (towards the left). This moves the first stage piston 14 in a compression stroke toward the outlet 28, reducing the volume within the first stage chamber 12 and forcing the oxygen from the larger first stage chamber 12 into the smaller second stage chamber 16 through outlet 28, passage 30, check valve 32 and inlet 58. At the same time, the second stage piston 18 moves in an expansion stroke away from outlet 60 increasing the volume within the second stage chamber 16 to be in an open position for receiving the oxygen expelled or discharged from the first stage chamber 12, as seen in FIG. 2. Check valve 24 prevents oxygen from exiting the first stage chamber 12 through the inlet 27. Since the volume of the second stage chamber 16 is smaller than the volume of the first stage chamber 12, the oxygen forced within the second stage chamber 16 from the first stage chamber 12 increases in pressure.

The motor drive 45 then drives the pistons 14 and 18 in unison in the reverse or opposite direction (to the right) so that the second stage piston 18 moves in a compression stroke toward outlet 60, decreasing the volume therein and forcing the oxygen from the second stage chamber 16 (FIG. 1) through outlet 60, check valve 48, past outlet pressure sensor 50, through line 46 and into tank 52. At the same time, the first stage piston 14 moves in an expansion stroke away from outlet 28 increasing the volume within the first stage chamber 12 to be in the open position for receiving oxygen from the home oxygen concentrator 20. Check valve 32 prevents oxygen from exiting the second stage chamber 16 through the inlet 58. The smaller diameter of the second stage piston 16 allows pump 10 to further increase the pressure of the oxygen that is pumped into tank 52. The oxygen pumped into tank 52 can reach pressures of about 2200 psi. The pressurized oxygen expelled from the second stage chamber 16 or contained within the tank 52 is prevented from re-entering the second stage chamber 16 by check valve 48. Check valves 24 and 32, in combination with check valve 48, keep the flow of gas through pump 10 moving in one direction.

When the first stage piston 14 is in the open position, controller 62 can be programmed to reactivate drive system 45 for another cycle only if the inlet pressure

sensor 26 detects a sufficient amount of oxygen. When the outlet pressure sensor 50 senses that the oxygen within tank 52 has reached a desired predetermined level, controller 62 can be programmed to deactivate drive system 45 so that the full tank 52 can be disconnected from the pump 10. An empty or partially empty tank 52 can then be connected to pump 10 for filling with oxygen.

Pump 10 is now described in further detail. Typically, chambers 12 and 16 are in a housing 11. Housing 11 can include hollow cylindrical members forming chambers 12 and 16 or can include one or more blocks with bores formed therein to form chambers 12 and 16. The threaded screw 38 forms a connecting member for securing the first stage piston 14 to the second stage piston 18 and can be fully threaded, or alternatively, partially threaded. In the embodiment shown, drive system 45 includes a reversible drive motor 40 which rotates ball screw nut 42 about threaded screw 38 and around axis A. The ball screw nut 42 is constrained to a fixed position along axis A so that rotation of ball screw nut 42 drives the threaded screw 38 longitudinally or linearly along axis A. The ball screw nut 42 has friction reducing balls which engage the threads of threaded screw 38 in a rolling manner, thereby reducing friction forces between the ball screw nut 42 and the threaded screw 38. This minimizes power losses when the rotational motion of the ball screw nut 42 is converted into linear motion of the threaded screw 38, and also minimizes the generation of heat therebetween.

Typically, the motor 40 is connected to the ball screw nut 42 by a power transmission 41 which converts rotational motion provided by motor 40 into rotational motion of ball screw nut 42. The power transmission 41 can be any suitable power transmission, such as a low backlash gear set, a timing belt/pulley set, etc. The motor 40 is typically a reversible electric motor. The stroke S (FIG. 1) of the pump 10 can be controlled by position sensors 34 and 36 of a piston position sensing system positioned at opposite ends of one of the chambers 12 or 16, for example, at opposite ends on the sides of chamber 12 as shown. Position sensors 34 and 36 are in communication with controller 62. In FIGs. 1 and 2, position sensors 34 and 36 detect the presence of the piston 14 when the piston reaches an end of chamber 12, thereby causing controller 62

to stop motor 40 and when desired, reverse direction. Motor 40 can be a servo or stepper motor which can be programmed to rotate a required angular amount for moving the pistons 14 and 18 in the desired stroke S. The rotational speed of motor 40 can be programmed to ramp up at the start of the stroke S and then ramp down at the end of the stroke. Even when motor 40 is programmed to move pistons 14 and 18 in the desired stroke, position sensors 34 and 36 can be employed to ensure that pistons 14 and 18 always stop in the proper location, but if desired, position sensors 34 and 36 can be omitted.

The size and rotational speed of motor 40, the transmission ratio of the power transmission 41 between the motor 40 and the ball screw nut 42, the threads per inch or thread pitch of the threaded screw 38, and the piston sizes and stroke lengths, can be selected to provide the desired pumping speed, power consumption and overall size of pump 10, depending upon application at hand. Embodiments of pump 10 are typically more efficient then prior pumps because less energy is lost to friction, and therefore can use substantially less power, run cooler, and can be much quieter than prior pumps. In addition, the use of a ball screw for reciprocating the pistons 14 and 18 makes use of a high degree of mechanical advantage so that a relatively small motor 40 can be used which further uses less power and generates less heat. Since the gas pumped by pump 10 can increase in pressure in two stages, a much smaller motor can be used in comparison to a pump that only has one stage.

In the embodiment shown in FIGs. 1 and 2, pistons 14 and 18 are sealed by respective pairs of seals 54 and 56, for example O-rings. The size of the diameters of the first stage piston 14 and the second stage piston 18 and the resulting diameter ratio can be selected to obtain the desired directional loading. In some cases, it can be desirable to size the diameters of the first 14 and second stage 18 pistons so that the power required to translate the pistons 14 and 18 is approximately the same in both directions. In one such embodiment of pump 10, the first stage piston 14 can have a diameter of about 4 inches, the second stage piston 18 can have a diameter of about 1.127 inches, and the stroke of the pistons can be about 6 inches. This results in a

diameter ratio of about 3.5 to 1 between the first stage piston 14 and the second stage piston 18. In addition, this results in a gas volume ratio of about 12.5 to 1 between the first stage chamber 12 and the second stage chamber 16. With such dimensions, about .5 $in.^3$ of gas at 2200 psi can be pumped per cycle.

Although pump 10 has been described and shown in FIGs. 1 and 2 for pumping oxygen, it is understood that pump 10 can be used to pump a number of different gases, for example, other medical gases such as nitrous oxide, non-therapeutic gases such as lethal gases, recreational gases such as helium, or gases for industrial or scientific use. In addition, it is understood that pump 10 can pump other fluids such as liquids. Depending upon the application at hand and the fluid pumped, pump 10 can be operated continuously. In addition, pressure sensor 26 and/or pressure sensor 50 can be omitted or replaced with timers, or an on/off switch.

Although FIGs. 1 and 2 depict threaded screw 38 being positioned between pistons 14 and 18 and extending through the inwardly positioned ends of chambers 12 and 16, alternatively, threaded screw 38 can be extended from one of the pistons 14 and 18 through a seal in the outwardly positioned ends of the respective chamber 12 or 16. In such a case, the drive system 45 would be positioned beyond the outward end of the chamber 12 or 16 on one side of the pump 10 to drive the threaded screw 38 extending therefrom. This would allow the first 12 and second 16 stage chambers to be positioned closer together whereby the connecting member between the pistons 14 and 18 can be an extension of one of the pistons. Although drive system 45 typically includes a rotating ball screw nut 42, in some low cost embodiments, a conventional rotatable threaded nut might be suitable. In other embodiments, the drive system 45 for driving pistons 14 and 18 can be replaced by or include other motion transmission mechanisms, such as a rack and pinion mechanism, a worm gear reducer, a crank slider mechanism, a cam mechanism, a hydraulic motor or piston, etc. Depending upon the mechanism used for driving the pistons 14 and 18, in some situations, the pistons 14 and 18 do not have to be aligned on a common axis. In addition, pistons 14 and 18 can be driven by separate drive systems.

While this invention has been particularly shown and described with references to particular embodiments thereof, it will be understood by those skilled in the art that various changes in form and details may be made therein without departing from the scope of the invention encompassed by the appended claims.

For example, although some dimensions have been given as examples in one embodiment of pump 10, it is understood that a variety of different dimensions are possible, depending upon the application at hand. In particular, the diameters of the pistons 14 and 18 can be varied. In addition, the diameter ratio of pistons 14 and 18 can be varied as well as the stroke length. The inlets and outlets to the first 12 and second stage 16 chambers can be positioned on the sides of the chambers and/or the axial ends, as desired. Passage 30 between the first 12 and second stage 16 chambers can be formed in the housing 11 or can be tubing extending between the two chambers. A passage between the first 12 and second stage 16 chambers can also be formed longitudinally through pistons 14 and 18 with a check valve positioned along the longitudinal passage. In other embodiments both sides of the pistons 14 and 18 can be employed for pumping so that each piston when moving, can simultaneously perform an expansion stroke on one side of the piston and a compression stroke on the other side. In such embodiments, additional appropriately positioned passages and check valves can be used as needed. Although the drive system 45 has been described as being connected to the threaded screw 38, the threaded screw 38 can be considered part of the drive system 45. Furthermore, although two pistons have been shown in FIGs. 1 and 2, particular embodiments can have more than two pistons for pumping fluid in additional stages for increased pressure, or for pumping fluid in parallel stages for increased flow.